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# **POLYMER FILM WITH OPTICALLY CONTROLLED FORM AND ACTUATION (PREPRINT)**

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14. ABSTRACT Polymer networks containing azobenzene liquid-crystalline (azo LC) moieties are capable of changing their macroscopic shape when influenced by light. Two distinct processes take place in azo LCs due to the photoisomerization of the azobenzene chromophores. Trans-cis isomerization and thus a reduced order parameter is dominant at UV wavelengths whereas trans-cis-trans isomerization processes are dominant at visible wavelengths resulting in orientation of the molecules perpendicular to the beam polarization.					
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# Polymer film with optically controlled form and actuation

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Polymer networks containing azobenzene liquid-crystalline (azo LC) moieties are capable of changing their macroscopic shape when influenced by light [1-4]. Two distinct processes take place in azo LCs due to the photoisomerization of the azobenzene chromophores. *Trans-cis* isomerization and thus a reduced order parameter is dominant at UV wavelengths whereas *trans-cis-trans* isomerization processes are dominant at visible wavelengths resulting in orientation of the molecules perpendicular to the beam polarization [5].

Bending of LC network films containing azobenzene chromophore was first demonstrated for UV light [1]. Bending of the film (towards the radiation source only), heated to 85°C, was induced by radiation of  $\lambda = 366$  nm wavelength. The initial shape could be restored with visible radiation ( $\lambda = 540$  nm) within several seconds. Two orders of magnitude faster photomechanical response was observed in a LC elastomer doped with an azo chromophore using argon-ion laser radiation [2] where a bending angle of  $\sim 67^\circ$  (towards radiation source) in a highly absorbing 320  $\mu\text{m}$ -thick material was achieved with 1.3 W power.

We recently reported the laser-induced photomechanical actuation of azo LC polymer films characterized by: 1) single wavelength operation; 2) reversible bi-directional bending ( $70^\circ < \alpha < 70^\circ$ ); 3) high speed of photoinduced deformation (170°/s); and 4) room temperature operation. These results were obtained for thin samples (10-50  $\mu\text{m}$ ) controlled with low power density radiation ( $\sim 0.1$  W/cm<sup>2</sup>) [3].

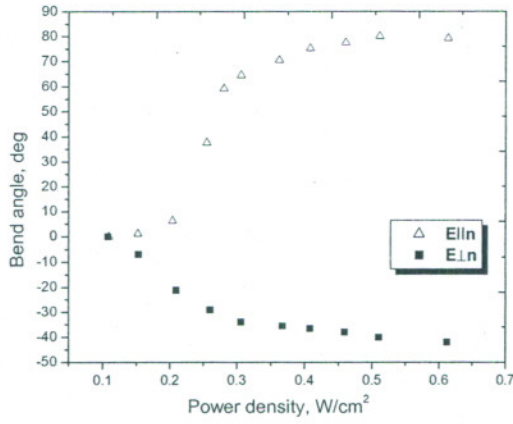
Two monomers, 4,4'-Di(6-acryloxyalkyloxy)azobenzene and the LC monomer 4-(6-acryloxy)hexyloxy-4'-ethoxyazobenzene were copolymerized according to [1]. Polymerization was performed between two glass substrates (10-50  $\mu\text{m}$ ) coated with poly(vinyl alcohol) and rubbed to create an easy-axis for the azo LC moieties. Rectangular slices of the polymer (removed from the substrates), a lower edge fixed to a platform, were exposed to a linearly polarized beam of a multimode cw argon-ion laser, expanded to the film size. The polymer film bends away or towards the laser for polarization perpendicular or parallel to the easy-axis, respectively. Figure 1 shows the magnitude of the bend angle for both polarizations as a function of power density and the deformation dynamics. Films could be reversibly bent towards and away from the incoming laser by switching the beam polarization. The complete oscillation for the extremes of bend angles ( $70^\circ < \alpha < 70^\circ$ ) was accomplished in  $\sim 1.3$  s.

The polarization dependence of the deformation sign results from the optically-induced realignment of LC chromophores which shrinks the volume of the polymer along the polarization direction and expands it along the direction perpendicular to it. Due to light attenuation caused by absorption and scattering, this effect is more efficient at the input surface of the incident beam causing the bending.

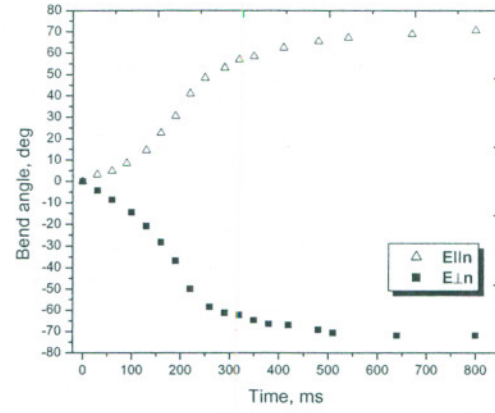
In summary, we report on the large and fast photomechanical actuation of a LC polymer film, operational at room temperature with bi-directionality of the mechanical response using a low power, single wavelength laser beam. This demonstration opens up interesting practical opportunities for controlling light beams, for adaptive optics, nonlinear optics, and lays the groundwork for enabling components for the next generation of Micro-Opto-Mechanical Systems.

## References

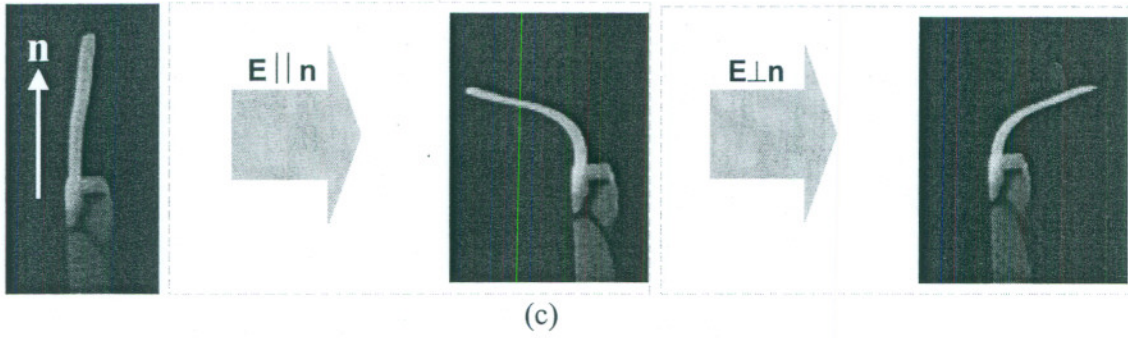
1. Y. Yu, M. Nakano, and T. Ikeda, "Directed bending of a polymeric film by light," *Nature* **425**, 145 (2003).
2. M. Camacho-Lopez, H. Finkelmann, P. Palffy-Muhoray, and M. Shelley, "Fast liquid-crystal elastomer swims into the dark," *Nature* **3**, 307-310 (2004).
3. N. V. Tabiryan, S. V. Serak, Xiao-Man Dai, T. J. Bunning, Polymer film with optically controlled form and actuation, *Optics Express*, **13**, 7442-7448, 2005.
4. K. D. Harris, R. Cuypers, P. Scheibe, C. L. van Oosten, C. W. M. Bastiaansen, J. Lub, and D. J. Broer, Large amplitude light-induced motion in high elastic modulus polymer actuators, *J. Mater. Chem.*, **15**, 5043-5048, 2005.
5. C. Kempe, M. Rutloh, and J. Stumpe, "Photo-orientation of azobenzene side chain polymers parallel or perpendicular to the polarization of red He-Ne light," *J. Phys.: Condens. Matter*. **15**, S813-S823 (2003).



(a)



(b)



(c)

Figure 1. (a) Bend angle of a polymer film (3 mm x 7 mm x 20  $\mu\text{m}$ ) as a function of power density of the laser beam (488 nm) for polarization parallel (open triangles) and perpendicular (dark triangles) to the LC orientation imposed at curing. (b) Deformation dynamics of the polymer film (1 mm x 7 mm x 20  $\mu\text{m}$ ) at a power density of 0.25 W/cm<sup>2</sup>. The azo LC polymer film shown in photos (c) is vertically attached to a platform. It bends away from the laser for a beam polarized perpendicular to the film orientation and towards the laser for a beam polarized parallel to the film orientation.